

Claims

1. A fuel processor comprised of a hydrogen generating apparatus, a single vessel heat-integrated multi-stage water-gas shift reactor, a multifunctional heat exchanger, a multiple
5 heat source boiler, and a single vessel water heat exchanged multi-staged preferential oxidation reactor, that provides hydrogen to a fuel cell stack and that is integrated by more than one means with said fuel cell stack.

10 2. The fuel processor according to claim 1 wherein said hydrogen generating apparatus is comprised of a combustion chamber, a burner, a steam reformer catalytic reactor, and a heat exchanger.

15 3. The hydrogen generating apparatus according to claim 2 wherein said combustion chamber has sufficient volume to provide a residence time, that is for the combustion products at normal temperature and pressure in the range of 1 second to 15 seconds, preferably 2 seconds to 10 seconds.

20 4. The hydrogen generating apparatus according to claim 2 wherein said combustion chamber is cylindrical with a length to diameter ratio in the range of 0.5 to 4.0, preferably from 1.0 to 3.0.

25 5. The hydrogen generating apparatus according to claim 2 wherein said combustion chamber has a burner mounted on the sidewall of said combustion chamber.

6. The combustion chamber according to claim 5 wherein said burner is a metal fiber burner operating in a high-intensity blue flame mode releasing the major part of the energy in a convective way.

7. The metal fiber burner according to claim 6 wherein said burner is a knitted metal fiber

burner.

8. The knitted metal fiber burner according to claim 7 wherein said burner operates at temperatures up to 1920°F.

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9. The knitted metal fiber burner according to claim 7 wherein said burner has a heating intensity from 900 kW/m² to 5000 kW/m² and preferably from 1000 kW/m² to 3000 kW/m².

10. The knitted metal fiber burner according to claim 7 wherein the metal fibers of said
burner are manufactured from a Fecralloy steel containing the following elements, iron,
chromium, aluminum, yttrium, silicon, manganese, copper, and carbon.

11. The knitted metal fiber burner according to claim 7 wherein said burner operates simultaneously with more than one fuel.

15 12. The knitted metal fiber burner according to claim 11 wherein one of said fuels is a hydrocarbon and the other is a mixture of gases containing carbon dioxide and hydrogen.

20 13. The mixture of gases containing carbon dioxide and hydrogen according to claim 11 wherein said mixture is obtained by a means of integrating the fuel processor with a fuel cell stack and said mixture is the anode off-gas from said fuel cell stack.

14. The fuels according to claim 11 wherein the hydrocarbon is one of the following,
liquefied petroleum gas, natural gas, or diesel fuel and the mixture is the anode off-gas from a
fuel cell stack whose proportions of carbon dioxide, hydrogen, and other gases vary with the
operating conditions of said fuel cell stack.

15. The combustion chamber according to claim 5 wherein said burner is comprised of a ceramic material.

16. The ceramic burner according to claim 11 wherein said burner operates at temperatures up to 2100°F.

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17. The steam reformer according to claim 2 wherein the steam reforming catalyst is located within a U-shaped reaction vessel located inside combustion chamber according to claim 5.

10 18. The heat exchanger according to claim 2 wherein said heat exchanger is a double pipe heat exchanger transferring heat from the combustion chamber flue gas leaving the combustion chamber to the mixture of reactant gases being fed to a fixed bed of steam reforming catalyst, said heat exchanger being located at the top of the combustion chamber.

15 19. The fuel processor according to claim 1 wherein said single vessel heat integrated multi-staged water-gas shift reactor is comprised of two or more water-gas shift reactors, and a means of exchanging heat with a multi-functional heat exchanger.

20 20. The single vessel heat integrated multi-staged water-gas shift reactor according to claim 19 wherein at least one of the water-gas shift reactors within a single vessel is operated at a greater temperature and at least one other within the same vessel is operated at a lesser temperature.

25 21. The single vessel heat integrated multi-staged water-gas shift reactor according to claim 19 wherein the gas mixture leaving the water-gas shift reactor that is operated at the greater temperature is cooled by passing through a multi-functional heat exchanger prior to entering the water-gas shift reactor that is operated at the lesser temperature, during normal operating conditions.

22. The single vessel heat integrated multi-staged water-gas shift reactor according to
claim 19 wherein the gas mixture leaving the water-gas shift reactor that is operated at the
greater temperature is heated by multi-functional heat exchanger prior to entering the
water-gas shift reactor that is operated at the lesser temperature, during start-up conditions
5 while the water-gas shift reactor that is operated at the lesser temperature has a temperature
less than the temperature of the multiple heat source boiler of claim 1.

23. The fuel processor according to claim 1 wherein said multi-functional heat exchanger
is comprised of means of receiving and providing heat to a water-gas shift catalyst bed
10 operated at a greater temperature, a water-gas shift catalyst bed operated at a lower
temperature, a multiple heat source boiler, and a means of receiving heat from an electrical
device.

24. The multi-functional heat exchanger of claim 23 wherein said heat exchanger
receives heat from a process gas mixture exiting a water-gas shift reactor operating a
greater temperature returning said gas mixture at a lower temperature to a water-gas shift
reactor operating at a lower temperature and transfers said heat to water arriving from the
multiple heat source boiler of claim 1 and returning said water in the form of a water-vapor
mixture to said multiple heat source boiler, during normal operation.
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20 25. The multi-functional heat exchanger of claim 23 wherein said electrical device is an
immersion water heater physically located with said multi-functional heat exchanger.

26. The multi-functional heat exchanger of claim 23 wherein said heat exchanger
transfers heat generated by said electrical device to water arriving from the multiple heat
source boiler of claim 1 and returning said water in the form of a water-vapor mixture to said
boiler, during the initial start-up of said boiler, when the water temperature of said multiple
heat source boiler is less than its boiling point.
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27. The multi-functional heat exchanger of claim 23 wherein said heat exchanger transfers heat generated by said electrical device to the process gas mixture of claim 24 during the initial start-up operation when the temperature of the water-gas shift reactor operating at the lower temperature is less than the boiling point of the water in said multiple heat source boiler of claim 1.

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28. The multi heat source boiler of claim 1 wherein said boiler has multiple means of simultaneously receiving heat to generate steam from boiler feed water.

10 29. The boiler of claim 28 wherein one of the means of receiving heat is combustion gas mixture emanating from the double pipe heat exchanger of claim 18.

15 30. The boiler of claim 28 wherein one of the means of receiving heat is the process gas mixture emanating from the water-gas shift catalyst bed operated at lower temperature of claim 20.

20 31. The boiler of claim 28 wherein one of the means of receiving heat is water-vapor mixture emanating from the multi-functional heat exchanger of claim 23.

25 32. The fuel processor of claim 1, wherein said single vessel water exchanged multi-staged preferential oxidation reactor is comprised of multiple stages and each stage is comprised of parallel tubular reactors filled with fixed beds of preferential oxidation catalyst, means of adding air to each fixed bed of catalyst, and means of maintaining the appropriate reactor temperature including means of removing the exothermic heat of the preferential oxidation reaction, all being arranged in a shell and tube geometries.

33. The preferential oxidation reactor of claim 32 wherein at least two stages of fixed beds of catalyst are used.

34. The preferential oxidation reactor of claim 33 wherein the total amount of air is divided among the two stages in a proportion having a range from 90:10 to 30:70 and preferably from 80:20 to 40:60, where the first figure is the proportion that enters the first fixed bed and the second figure is the proportion that enters the second fixed bed.

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35. The preferential oxidation reactor of claim 32 wherein said means of maintaining the temperature of said reactor is a stream of water that is at the appropriate temperature.

36. The preferential oxidation reactor of claim 35 wherein said stream of water is obtained by a means of integrating the fuel processor with the fuel cell stack, more particularly it is the cooling water from a fuel cell stack that has been integrated with the fuel processing apparatus of claim 1.

37. The preferential oxidation reactor of claim 32 wherein said stream of water is passed over the shell side of the tubular reactors within the various stages of said preferential oxidation reactor.

38. The preferential oxidation reactor of claim 36 wherein said water stream exchanges heat initially with the first stage tubular reactors having fixed beds of catalyst and later with the last stage of tubular reactors having fixed beds of catalyst.

39. The preferential oxidation reactor of claim 36 wherein said water stream exchanges heat initially with the last stage of tubular reactors having fixed beds of catalyst and later with the first stage of tubular reactors having fixed beds of catalyst.

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